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PATENT & TRADEMARK OFFICE

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant	: Fuller et al.		
Serial No.	: 10/677,869	**: Group:**	1762
Atty. No	: DP 307055	**: Examiner:**	Bareford, K.A.
Filed	: October 2, 2003	**: Confirmation No.**	9840
Title	: CORRECTING DEFECTIVE KINETICALLY SPRAYED SURFACES		

BRIEF ON APPEAL

Mail Stop Appeal Brief - Patents
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

Dear Sir:

Subsequent to the filing of the Notice of Appeal dated September 7, 2005 by the OIPE, Applicants now submit a brief in support of the appeal in response to the Final Rejection set forth in the Office Action dated June 8, 2005. A single copy of this Appeal Brief is being submitted in accordance with 37 C.F.R. §41.37 and this Appeal Brief is accompanied by the required fee of $500.00 under §41.20(b).

The Patent Office is authorized to charge or refund any fee deficiency or excess to Deposit Account No. 08-2789.

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I. Real Party in Interest

The inventors assigned this application to the real party in interest Delphi Technologies, Inc. as evidenced by an assignment recorded at reel 01458, frame 0675.

II. Related appeals and interferences

There are no related appeals or interferences.

III. Status of claims

Independent claims 1 and 10 have previously been presented. Claims 2-8 and 11-16 are in original form. Claims 9 and 17 have been canceled. Claims 1, 2, 4, 6, 7, 10, 11, 14 and 15 have been finally rejected under 35 U.S.C. §102(e) based on Fuller et al. (US Pat. No. 6,743,468). Claims 3, 5, 12, and 13 have been finally rejected under 35 U.S.C. § 103 based on Fuller et al. Claims 1-4, 6-8, 10-12, and 14-16 have been finally rejected under 35 U.S.C. § 103 based on Brogan (US Publication No. 2002/0110682). Claims 8 and 16 have been finally rejected under 35 U.S.C. § 103 based on Fuller et al. in combination with Van Steenkiste et al. (US Pat. No. 6,139,913).

A set of the claims on appeal is found in the claims appendix.

IV. Status of amendments

All amendments have been entered and are reflected in the claims in the claims appendix.

V. Summary of claimed subject matter

A. Independent claim 1

Claim 1 is directed to a method for repairing a defect in a kinetically sprayed surface. In applying a coating to a surface using kinetic spraying methods it is not uncommon to develop a surface defect in the coating caused by the kinetic spray process. If this defect is not repaired and the kinetic spraying is continued the defect continues to expand and consumes a larger portion of the coating area. Therefore, it is essential that once detected the defect caused by the kinetic spraying process must be repaired prior to continuing to utilize a kinetic spray process to apply additional coating material. The present invention has developed a method for rapidly repairing these defects in a kinetically sprayed surface.

As mentioned claim 1 is directed to a method for repairing a defect in a kinetically sprayed surface comprising the steps of providing the kinetically sprayed surface having a defect in the surface caused by the kinetic spraying. A repair coating to the defect is applied by thermally spraying a molten material onto the defect by a thermal spray process selected from the group consisting of a High Velocity Oxy-Fuel combustion thermal spray process, a wire arc thermal spray process, a vacuum plasma thermal spray process, a flame spray thermal process, or a radio frequency plasma thermal spray process. The thermal spray process fills the defect thereby repairing it.

The specific limitations of independent claim 1 and the support for each in the specification are provided below in Table 1.

TABLE 1

Claim 1 limitations	Support for the limitation in the specification
A method for repairing a defect in a kinetically sprayed surface comprising the steps of providing a kinetically sprayed surface having a defect in the surface, said defect caused by said kinetic spraying,	Support for this limitation can be found in the specification at paragraphs [0024] through [0029] and within figures 3-6 of the specification.
applying a repair coating to the defect by thermally spraying a molten material on the defect by a thermal spray process selected from the group consisting of a High Velocity Oxy-Fuel combustion thermal spray process, a wire arc thermal spray process, a vacuum plasma thermal spray process, a flame spray thermal process, or a radio frequency plasma thermal spray process thereby, filling the defect and repairing the defect	Support for this limitation can be found in paragraph [0025], figure 6 , and paragraph [0030] of the specification.

B. Independent claim 10

Claim 10 is directed to a method for repairing a defect in a kinetically sprayed surface. This claim is similar to independent claim 1 with the additional step of adding an additional kinetically sprayed surface over the repaired defect once it has been repaired. As noted above when applying a coating to a surface using a kinetic spray process it is not uncommon for the coating to develop a defect within the kinetically sprayed surface. If this defect is not corrected the defect continues to grow in size resulting in a defective surface that must be discarded. The present invention comprises a method for repairing these defective surfaces such that the kinetic spray coating can continue to be applied. Claim 10 is directed to a method for repairing a defect in a kinetically sprayed surface comprising the steps of providing a kinetically sprayed surface having a defect in the surface caused by the kinetic spraying; applying a repair coating to the defect by thermally spraying a molten material onto the defect by a process selected from the group consisting of a High Velocity Oxy-Fuel combustion thermal spray process, a wire arc thermal spray process, a vacuum plasma thermal spray process, a flame spray thermal process, or a radio frequency plasma thermal spray process thereby filling the defect and repairing the defect; and applying an additional kinetically sprayed surface over the repaired defect.

The specific limitations of independent claim 10 and the support for each in the specification are provided below in Table 2.

TABLE 2

Claim 10 limitations	Support for the limitation in the specification
A method for repairing a defect in a kinetically sprayed surface comprising the steps of:	Support for this limitation can be found in the specification at

a) providing a kinetically sprayed surface having a defect in the surface, said defect caused by said kinetic spraying;	paragraphs [0024] through [0029] and within figures 3-6 of the specification.
b) applying a repair coating to the defect by thermally spraying a molten material on the defect by a process selected from the group consisting of a High Velocity Oxy-Fuel combustion thermal spray process, a wire arc thermal spray process, a vacuum plasma thermal spray process, a flame spray thermal process, or a radio frequency plasma thermal spray process thereby filling the defect and repairing the defect; and	Support for this limitation can be found in paragraph [0025], figure 6 and paragraph [0030] of the specification.
c) applying an additional kinetically sprayed surface over the repaired defect.	Support for this limitation can be found in the specification at paragraph [0029] and within the abstract.

VI. Grounds of rejection to be reviewed on appeal

Claims 1, 2, 4, 6, 7, 10, 11, 14 and 15 have been rejected under 35 U.S.C. § 102(e) based on Fuller et al. (US Pat. No. 6,743,468). Claims 3, 5, 12, and 13 have been rejected under 35 U.S.C. § 103 based on Fuller et al. Claims 8 and 16 have been rejected under 35 U.S.C. § 103 based on Fuller et al. and Van Steenkiste et al. (US Pat. No. 6,139,913). Claims 1-4, 6-8, 10-12, and 14-16 have been rejected under 35 U.S.C. § 103 based on Brogan (US Publication No. 2002/0110682). All of these grounds of rejection are to be reviewed on appeal.

VII. Argument

A. Rejection of claims 1, 2, 4, 6, 7, 10, 11, 14, and 15 under 35 U.S.C. § 102(e) based on Fuller et al.

Rejection of a claim under 35 U.S.C. § 102(e) requires that each and every limitation of the rejected claim be found within a single reference if even a single limitation is not found within the reference the rejection is inappropriate and must be withdrawn.

Independent claim 1 is directed to a method for repairing a defect in a kinetically sprayed surface and requires first providing a kinetically sprayed surface having a defect in the surface caused by the kinetic spraying and then applying a repair coating to the defect by thermally spraying a molten material on the defect by a thermal spray process selected from the group consisting of a High Velocity Oxy-Fuel combustion thermal spray process, a wire arc thermal spray process, a vacuum plasma thermal spray process, a flame spray thermal process, or a radio frequency plasma thermal spray process thereby filling the defect and repairing the defect.

Fuller et al. is directed toward a system that provides an operator with a single system capable of applying both a kinetic spray coating layer and a thermal spray layer onto a substrate using a single application nozzle. The system relies on a higher heat capacity gas heater to permit oscillation between a kinetic spray mode and a thermal plasma spray mode as the only thermal spray mode capable of utilizing the system. Fuller et al. provides no disclosure of the ability of utilizing the disclosed single nozzle or system for any of the specific types of thermal spray processes recited within independent claim 1 of the present invention. All of the thermal spray processes recited in independent claim 1 requires specific thermal spraying equipment other than that disclosed in Fuller et al. The Examiner had suggested that the system of Fuller et al. could be used as a High Velocity Oxy-Fuel combustion thermal spray system.

Attached as Exhibit A of the evidence appendix is a portion of the book entitled "Equipment and Theory A lesson from THERMAL SPRAY TECHNOLOGY", course 51, lesson, test 2 by Dr. Ronald W. Smith, P.E., edited by Brooke Willis, Material Engineering Institute, ASM International®, published in 1992, pages 18-22. This exhibit, shows the actual equipment and designs utilized in a High Velocity Oxy-Fuel combustion spray process. When the response to the final rejection was filed this Exhibit was included. In a follow-up phone call after the Advisory Action was mailed the Examiner acknowledged that it had been sent with the response. However, the Examiner failed to see it and review it prior to issuing the Advisory Action. None of the system disclosed in Fuller et al. is capable of carrying out a High Velocity Oxy-Fuel combustion thermal spray process as can be seen from the attached exhibit. The recited thermal spray processes in claim 1 cannot be conducted using the system disclosed in Fuller et al.

In the advisory action the Examiner pointed to Browning (US Pat. No. 5,330,798) as providing a High Velocity Oxy-Fuel combustion thermal spray nozzle system with an expanding super sonic nozzle and a combustion chamber. The Examiner suggested this showed that Fuller et al. could be used to provide a

High Velocity Oxy-Fuel combustion thermal spray process. As a first matter it is irrelevant what an additional reference discloses because the rejection is under 102(e) and requires utilization of a single reference. Thus, irrespective of what Browning shows it cannot be utilized in this rejection. Secondly, a review of Browning discloses that it is not in fact a thermal spray process at all. What Browning discloses is utilization of a oxi-fuel or air-fuel thermal spray system in combination with a cooling coil to provide a kinetic spray system. Specifically, Browning teaches utilization of his system to lower the jet temperature to a temperature well below the melting point of the material being sprayed such that the material is rendered solid prior to impact on a substrate or workpiece. The Examiner is directed to Browning column 1, lines 13-20; column 2, lines 5-12; column 2, lines 17-31; and column 3, lines 20-35. Throughout Browning discloses utilizing his system to generate a supersonic jet that is cooled prior to introduction of the particles to be sprayed into the jet stream. Thus Browning does not disclose a High Velocity Oxy-Fuel combustion thermal spray process that deposits a molten material onto the defect as required by independent claim 1. In summary, claim 1 includes several limitations not found within the cited reference of Fuller et al. thus the rejection of claim 1 and the claims which depend therefrom under 35 U.S.C. § 102(e) based on Fuller et al. is improper and should be withdrawn.

Independent claim 10 includes all the limitations of independent claim 1 and the additional limitation of applying an additional kinetically sprayed surface over the repaired defect. Thus, the rejection of independent claim 10 and the claims which depend therefrom under 35 U.S.C. § 102(e) based on Fuller et al. is improper and must be withdrawn for the reasons stated above with respect to the rejection of claim 1 based on Fuller et al. under 35 U.S.C. § 102(e).

B. Rejection of claims 3, 5, 12, and 13 under 35 U.S.C. § 103 based on Fuller et al.

Fuller et al. only qualifies as prior art under 35 U.S.C. § 102(e). Thus its utilization under 35 U.S.C. § 103 can be overcome based on 35 U.S.C. § 103(c). The subject matter disclosed in Fuller et al. and the presently claimed invention were, at the time the presently claimed invention was made, owned by the same person or subject to an obligation of assignment to the same person, namely Delphi Technologies, Inc. and in fact have been so assigned. Therefore, the rejection of claims 3, 5, 12, and 13 under 35 U.S.C. § 103 based on Fuller et al. cannot be maintained and must be withdrawn.

C. Rejection of claims 8 and 16 under 35 U.S.C. § 103 based on Fuller et al. in view of Van Steenkiste et al.

As noted above Fuller et al. is inapplicable to the present invention as a rejection basis under 35 U.S.C. § 103. The cited reference of Van Steenkiste et al. is solely directed toward a conventional kinetic spray coating method and apparatus. There is no disclosure within Van Steenkiste et al. of defects in kinetically sprayed surfaces caused by kinetic spray application. There is no disclosure in Van Steenkiste et al. of any thermal spray processes or their utilization for repairing defects in surfaces caused by kinetic spray processes. Because there is no teaching, suggestion, or motivation within Van Steenkiste et al. for modifying Van Steenkiste et al. thereby making obvious any of the limitations of independent claims 1 or 10 which dependent claims 8 and 16 depend from the rejection of these claims under 35 U.S.C. § 103 based on Van Steenkiste et al. must be withdrawn.

D. Rejection of claims 1-4, 6-8, 10-12 and 14-16 under 35 U.S.C. § 103 based on Brogan.

The Examiner suggests that Brogan teaches the possibility of a kinetically sprayed surface. The Examiner points to paragraphs 29 and 69-70 of Brogan. The Examiner suggests that in paragraph 29 Brogan suggests that the term "thermal spraying" encompasses cold gas dynamic spraying. This is simply a incorrect use of the term. In the art there is a clear difference between cold gas dynamic spraying and thermal spraying. Thermal spraying always involves and is defined in the present specification as involving thermal softening of the materials being sprayed such that they are reduced to a molten state prior to their application to a surface. Cold gas dynamic spraying which is equivalent to kinetic spraying always means that there is no thermal softening of the particles being sprayed and that they strike a surface to be coated in the same physical state as they began. In paragraph 30 of Brogan, Brogan clearly identifies what is meant by "thermal spraying" in the context of his disclosure. Brogan states:

> "In the context of the present invention, the term "thermal spraying" is intended to include spraying of a polymer or polymer particulate with such velocity that its kinetic energy is sufficient to soften/melt the polymer or polymer particulate upon impact with a surface resulting in a coalesced coating of polymer on the surface. The term "thermal spraying" is also meant to encompass any known method of depositing an organic containing material, such as a polymer, onto a surface wherein the organic containing material is heated above the ambient temperature to a point where it softens and/or

> melts so that is may be deposited on a surface by a stream of propelling gas impinging on the organic containing material."

Brogan as his own lexicographer clearly provided the definition for terms as utilized in his specification. The words utilized make it clear that Brogan is not disclosing a kinetic spraying process. With respect to paragraphs 69-70, this also does not disclose a kinetically sprayed surface. In this section Brogan discusses heating a surface to melt the existing covering and then thermally spraying onto that covering. This is also unlike the present invention. What Brogan is disclosing is repair of worn and damaged surfaces using a thermal spray comprising a polymer and an aggregate. Thus, nowhere within Brogan is there found a suggestion, teaching, or motivation for modifying Brogan to make obvious the method as claimed in independent claim 1 of the present invention. Specifically, Brogan does not teach, suggest, nor make obvious providing a kinetically sprayed surface with a surface defect therein caused by the kinetic spray process and repair of this defect utilizing a thermal spray process selected from a specific group of thermal spray processes as required by independent claim 1. Because Brogan does not make obvious each and every limitation of independent claim 1, the rejection of independent claim 1 and the claims which depend therefrom under 35 U.S.C. § 103 based on Brogan is improper and must be withdrawn.

As noted above independent claim 10 is identical to independent claim 1 with the additional limitation of applying an additional kinetically sprayed surface over the repaired defect. The Examiner nowhere discusses why one of ordinary skill in the art would modify Brogan to include this third step in the method. As noted above

Applicants argue that Brogan does not even disclose a kinetic spray process. What Brogan discloses is a thermal spray process utilizing a combination of a polymer and an aggregate. The only repair disclosed in Brogan is repair of worn and damaged surfaces using a thermal spray process. Brogan does not disclose a kinetic spray process, does not disclose repair of a kinetic sprayed surface that is damaged by kinetic spray process, and does not disclose further utilizing a kinetic spray process to cover the repaired defect. All these limitations of claim 10 are critical and none of them are obvious based on the disclosure of Brogan. Because independent claim 10 includes numerous limitations neither found in nor made obvious based on the disclosure of Brogan rejection of this claim and the claims which depend therefrom under 35 U.S.C. § 103 based on Brogan is improper and must be withdrawn.

Respectfully submitted,

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November 7, 2005
Date

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CERTIFICATE OF EXPRESS MAILING

I hereby certify that the attached Appeal Brief for application serial number 10/677,869 filed October 2, 2003 is being deposited with the United States Postal Service as Express Mail EV 564947175 in an envelope addressed to Mail Stop Appeal Brief – Patents, Commissioner of Patents, P.O. Box 1450, Alexandria, Virginia 22313-1450, on this **November 7, 2005**.

Rainie Mills

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VIII. Claims appendix

1. (Previously presented) A method for repairing a defect in a kinetically sprayed surface comprising the steps of providing a kinetically sprayed surface having a defect in the surface, said defect caused by said kinetic spraying, applying a repair coating to the defect by thermally spraying a molten material on the defect by a thermal spray process selected from the group consisting of a High Velocity Oxy-Fuel combustion thermal spray process, a wire arc thermal spray process, a vacuum plasma thermal spray process, a flame spray thermal process, or a radio frequency plasma thermal spray process thereby, filling the defect and repairing the defect.

2. (Original) The method of claim 1, wherein the molten material is formed from the same material as the kinetically sprayed surface.

3. (Original) The method of claim 1, wherein the molten material has a different material composition from the kinetically sprayed surface.

4. (Original) The method of claim 1, comprising the further step of applying an additional kinetically sprayed coating over the thermally sprayed once molten material.

5. (Original) The method of claim 1, wherein the kinetically sprayed surface has a thickness of at least 5 millimeters.

6. (Original) The method of claim 1, wherein the defect comprises at least one conical defect.

7. (Original) The method of claim 1, wherein the molten material comprises at least one of a metal or an alloy.

8. (Original) The method of claim 7, wherein the molten material comprises a nickel and copper alloy.

9. (Cancelled)

10. (Previously presented) A method for repairing a defect in a kinetically sprayed surface comprising the steps of:

a) providing a kinetically sprayed surface having a defect in the surface, said defect caused by said kinetic spraying;

b) applying a repair coating to the defect by thermally spraying a molten material on the defect by a process selected from the group consisting of a High Velocity Oxy-Fuel combustion thermal spray process, a wire arc thermal spray process, a vacuum plasma thermal spray process, a flame spray thermal process, or a radio frequency plasma thermal spray process thereby filling the defect and repairing the defect; and

c) applying an additional kinetically sprayed surface over the repaired defect.

11. (Original) The method of claim 10, wherein step b) comprises using a molten material formed from the same material as the kinetically sprayed surface.

12. (Original) The method of claim 10, wherein step b) comprises using a molten material having a different material composition from the kinetically sprayed surface.

13. (Original) The method of claim 10, wherein the kinetically sprayed surface provided in step a) has a thickness of at least 5 millimeters.

14. (Original) The method of claim 10, wherein step a) comprises providing a defect comprising at least one conical defect.

15. (Original) The method of claim 10, wherein step b) comprises using a molten material comprising at least one of a metal or an alloy.

16. (Original) The method of claim 15, wherein the molten material comprises a nickel and copper alloy.

17. (Cancelled)

IX. Evidence appendix

ASM INTERNATIONAL
The Materials Information Society

Part B

Equipment and Theory

A lesson from THERMAL SPRAY TECHNOLOGY

by
Dr. Ronald W. Smith, P.E.

Course 51
Lesson, Test 2

MEI MATERIALS ENGINEERING INSTITUTE

Metric Conversion Factors

To convert from	To	Multiply by
in.	mm	25.4
in.	m	25.4×10^{-3}
mil	µm	25.4
µin.	µm	25.4×10^{-3}
in.^{2}	m^2	6.45×10^{-4}
in.^{3}	m^3	1.64×10^{-5}
ft.	m	3.048×10^{-1}
ft.^{2}	m^2	9.29×10^{-2}
ft.^{3}	m^3	2.831×10^{-2}
oz.	g	2.834×10^{1}
lb.	kg	4.536×10^{-1}
Btu	J	1.054×10^{3}
Btu/lb. • °F	J/kg • K	4.18×10^{3}
Btu/ft. • hr • °F	W/m • K	1.730
10 in./in./°F	10^{-6} mm/mm/°C	1.8
psi	Pa	6.895×10^{3}
psi	kPa	6.895
ksi	kPa	6.895×10^{3}
ksi	MPa	6.895
ksi • in.$^{1/2}$	MPa • m$^{1/2}$	1.099
ksi$\sqrt{\text{in.}}$	MPa • $\sqrt{\text{m}}$	1.099
oz.f	gf	28.4
lbf	kgf	4.536×10^{-1}
lbf	N	4.448
lbf • ft.	N • m (or J)	1.356
lbf/in.^{2}	kgf/cm^2	14.223
lbf/in.^{3}	kgf/m^3	2.768×10^{4}
lb./ft.^{3}	kg/m^3	16.019
lb./in.^{3}	g/cm^3	2.768×10^{1}
lb./in.^{3}	kg/m^3	2.768×10^{4}
gal (U.S. liquid)	L	3.785
gal (U.S. liquid)	m^3	3.785×10^{-3}
lb./gal	g/L	119.826
ft./gal	ml/L	748
°F	°C	(°F − 32)/1.8
°F	K	(°F + 459.67)/1.8
°C	°F	(°C • 1.8) + 32
°C	K	°C + 273.15
K	°C	°C − 273.15

Multiple and Submultiple Units

10^{18}	exa (E)	10^{-1}	deci (d)
10^{15}	peta (P)	10^{-2}	centi (c)
10^{12}	tera (T)	10^{-3}	milli (m)
10^{9}	giga (G)	10^{-6}	micro (µ)
10^{6}	mega (M)	10^{-9}	nano (n)
10^{3}	kilo (k)	10^{-12}	pico (p)
10^{2}	hecto (h)	10^{-15}	femto (f)
10^{1}	deka (da)	10^{-18}	atto (a)

Abbreviations

J	joule	m	meter	Pa	pascal
kgf	kilogram force	mm	millimeter	K	kelvin
L	liter	N	newton	W	watt

by

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Editor

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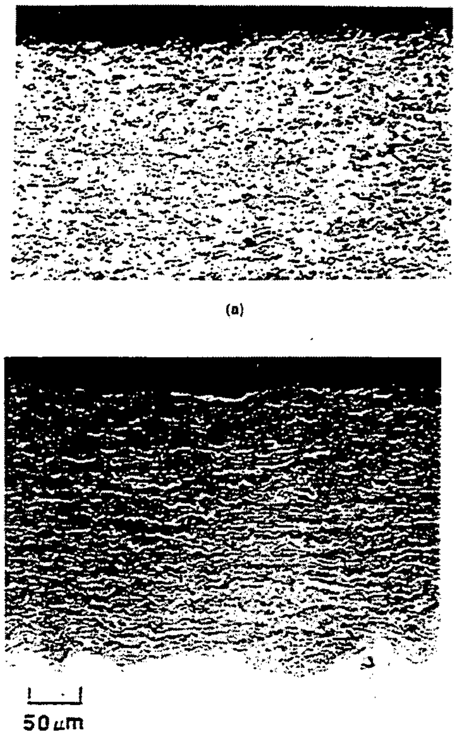
duces some of thermal spray industry's densest and highest bond-strength coatings. A large number of commercial aircraft engine wear coatings specify the process. It has also been shown that a higher degree of retained carbides found in D-Gun cermet (carbide) coatings, when compared to flame and plasma spray coatings, contribute to the D-Gun coating's higher hardness values. The higher retained carbide is due again to reduced oxidizing atmosphere of the D-Gun confined combustion zone which retain a high partial pressure of carbon in the atmosphere.

High-Velocity Oxyfuel Spray (HVOF)

Process. The high-velocity oxyfuel (HVOF) spray process was invented in 1958 by Smith et al. of Union Carbide, and commercially introduced in 1974 by Browning. The HVOF spray process is similar to the D-Gun process, with internal, confine combustion; however, the combustion gases are fed and combusted continuously. Gases include oxygen in combination with fuels such as propylene (C_3H_6), hydrogen, MAP, propane, and even liquid fuels such as kerosene. HVOF guns have combustor sections (air or water cooled) which combusts the fuel/oxygen mixtures under pressure and accelerates the combusted gas streams down a confined, cooled tube. Powders, with carrier gases, are fed into the nozzle where the particles are entrained with the confined, high-pressure combusting gases.



(a)

(b)

Figure 19. Typical D-Gun coating microstructures. (a) WC/Co and (b) Al_2O_3 + TiO_2. *(Courtesy, Praxair)*

The gun schematic in Figure 20 illustrates the basic HVOF features which incorporate an internal combustion, active gun cooling, particle injection into a tube with the high-pressure combusting gases, and a rapid supersonic nozzle expansion of the combusting gases. Particle heat transfer and efficiency and particle dwell times are increased by this design. HVOF's gas acceleration, higher than conventional combustion or even plasma, has also been shown to increase particle velocities with corresponding increases in coating density, coating adhesion, and with finer coating oxide inclusion distributions. Lower average particle temperatures, compared to plasma spray, likely reduces the degree of particle melting and oxidation. Yet despite the lower average particle temperatures, high coating densities are still achieved through HVOF's high particle impact velocities which easily deform particles that may not have been well melted.

Equipment. HVOF with the internal combustor requires active cooling systems and in addition has gas flow controls for much higher gas flow rates compared to conventional flame spray. These components are found to be important for managing HVOF's thermal input and for improving its control over the more conventional combustion processes.

Components. The key HVOF components are:

- Oxygen/fuel gas control mixtures (high flows);
- Powder injector;
- Powder gas flow control;
- Water circuit or air cooling;

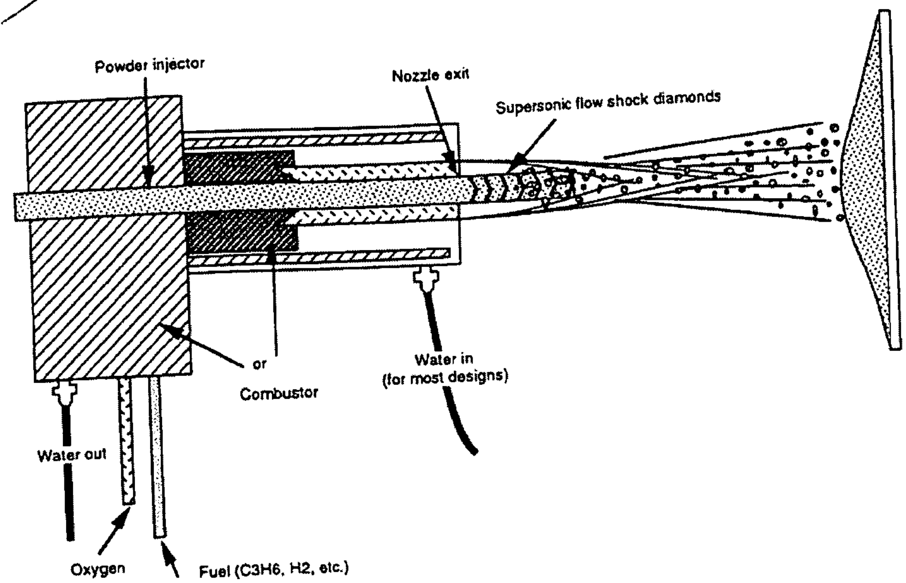


Figure 20. HVOF thermal spray gun.

- Nozzle cooling flow & control;
- Cooling passages;
- Nozzle tube/exit nozzle;
- Combustion gas injectors; and
- Fuel pumps (for liquid fuel systems).

HVOF equipment components differ further from conventional flame spray equipment by the added cooling, higher-pressure combustion gas delivery systems, and the powder delivery. The high gas flow rates and the criticality of combustion fuel mixtures require more precise gas flow systems; thus, rotometers have been replaced by high-flow-rate impact meters, critical flow orifices and/or mass flowmeter systems. The nozzle tube in combination with the combustor require the tubes/injectors to be cooled. Cooling in HVOF nozzles has been found to be critical in most devices for preventing the combustion products or molten/vaporized powder from depositing onto tube walls and for preventing tube thermal distress. Secondly, the high energy densities of HVOF torches put stress on components, increasing wear and creating component replacement needs not seen in the conventional flame spray processes. Thus, in the water-cooled designs, coolant temperature and flow-control feedback are necessary for obtaining consistent deposition quality. Finally, powder delivery and combustion gas injection is more precise in HVOF than in conventional flame spray in order to better control the thermal input to the distribution of powder particles.

HVOF spray coating processes are separated into four major designs: 1) internal combustion with the hot gases directed into a chamber where it mixes with and heats a mixture of carrier gas and powder particles; 2) simultaneous injection of powder into a combustion chamber where the mixture continuously burns and heats the particles; 3) confined combustion into which a stream of powder with carrier gas is injected; and 4) high-pressure liquid fuel systems with radial injection of powders downstream of the combustor exit. Figure 21 illustrates these various designs, showing the major differences between them; compare to the D-Gun process shown in Figure 18. Common to all HVOF methods is that the gases

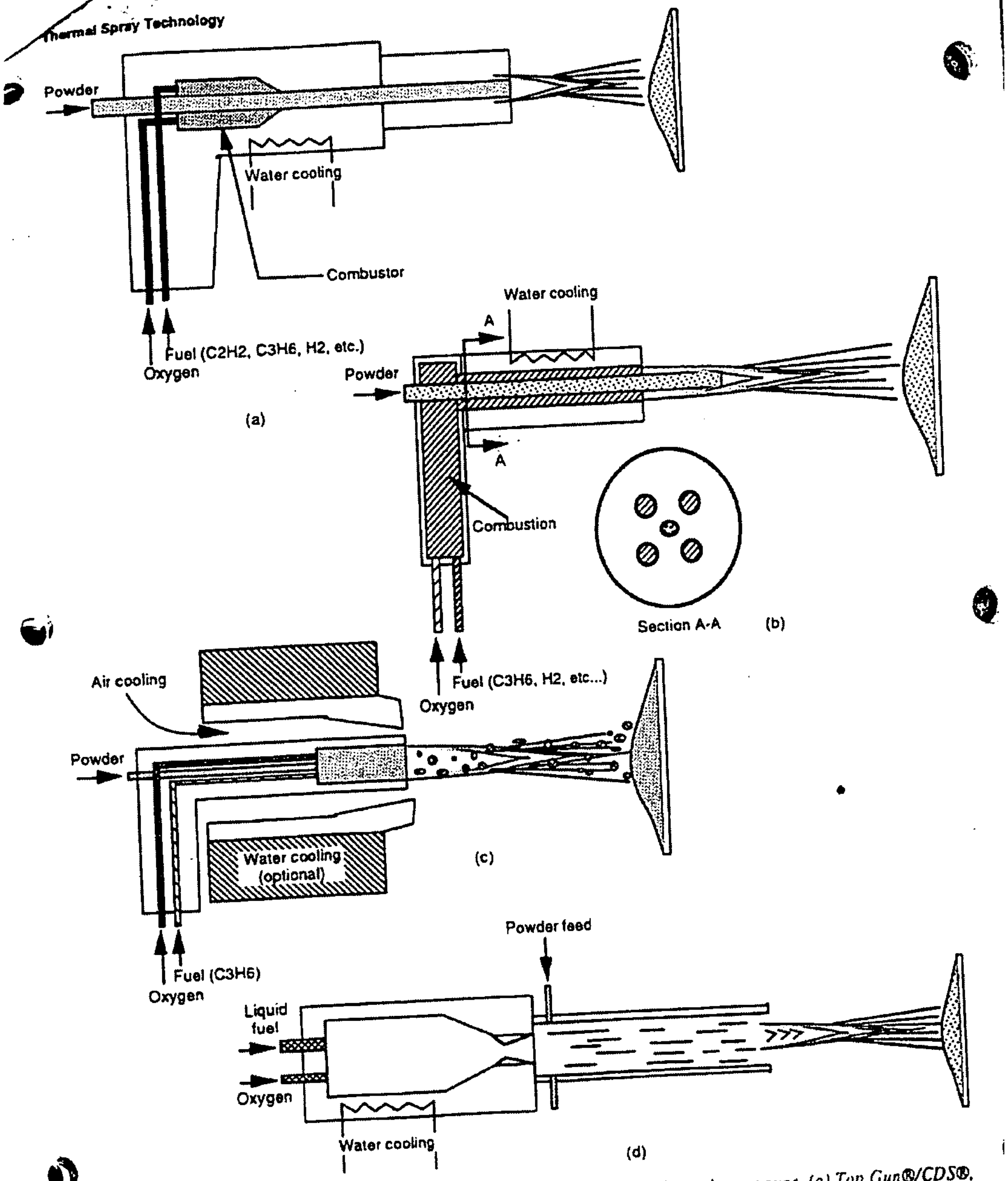
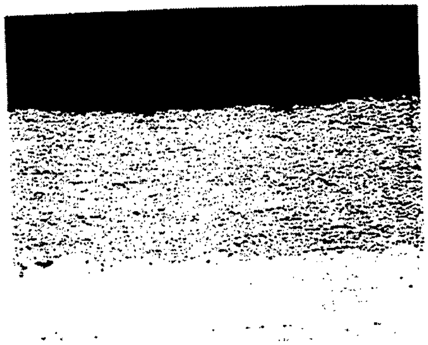


Figure 21. Operational principles of several commercially available HVOF thermal spray guns. (a) Top Gun®/CDS®, etc.. (b) Jet Kote®. (c) Diamond Jet (D-J®) and (d) J-P 5000®.

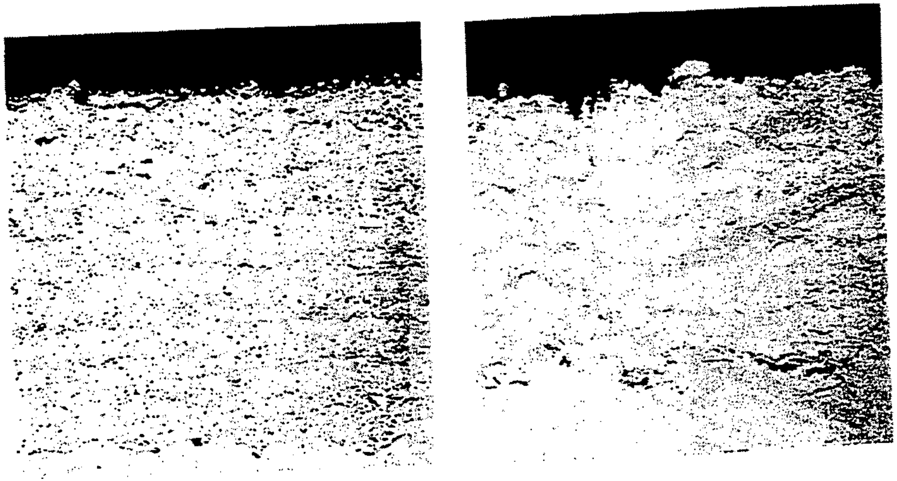
are being burned under higher-than-atmospheric pressures with the combustion gases, carrier gas, and an entrained distribution of powders being accelerated in the tube. The length of the nozzle, the design of heating chambers, the geometry/location of powder feed, and the cooling, either by water or air, are the major features which differ.

High nozzle gas flows, typically 150 to 300 slm (320 to 640 scfh) of oxygen and 200 to 600 slm (430 to 1280 scfh) of fuel gases, are typically fed into devices which all have supersonic expansion. The high velocity, high density gas flows accelerate the gases and powder particles to velocities much closer to the gas velocity compared to other thermal spray processes. The gas exit velocities are so high that most HVOF processes have noticeable, multiple "shock" diamond-shaped patterns in the gas jets which is denote rapid gas density changes in the luminous jets structures, indicating the supersonic nature of the exit gas velocities. The number of shock diamonds, although related to gas velocity, is not directly an indication of Mach number (gas velocity relative to velocity of sound). Investigators have calculated and, in some cases measured gas exit velocities from Mach 1 to Mach 2, which for the given gas and temperatures in HVOF spraying, is approximately 1000 m/s (3280 ft./s).

Deposit Characteristics. Reportedly, the HVOF coating structure and hardness values are comparable to D-Gun coatings. HVOF-sprayed coating density, adherence and oxide content and compare



(a)



(b)

(c)

Figure 22. Typical microstructures of HVOF sprayed coatings, (a) WC/Co, (b) Cr_3C_2/NiCr carbide and (c) 316 stainless steel. (Courtesy, Metco, Hobart Tafa Technologies and Miller Thermal, respectively)

favorably with many plasma-sprayed coatings. Supersonic acceleration of combustion gas/particle mixtures has added new capability and is offering new opportunities for combustion spraying. HVOF coating bond strengths have been reported over 83 MPa (12 ksi), and coating densities over 98% are reported for materials such as WC/Co and many metals. Compositional analysis of WC/Co coatings show that, compared to plasma spray, only a small degree of WC decomposition has occurred, thus preserving the material's intrinsic hardness values. Table 1 summarized HVOF's attributes, including the higher particle velocities and the lower heating temperatures of HVOF compared to plasma spray. These HVOF features are mainly responsible for the lower degree of WC decomposition.

Figure 22 shows some examples of HVOF coating microstructures, showing the finer oxide dispersions, denser and finer splat structures, and the high carbide retention. The excellent bonding, high coating densities, and the homogeneous coating structures of HVOF-sprayed coatings is now renewing commercial interest in combustion spray methods. HVOF appears to be a high growth area and many applications are now reconsidering combustion spray processes in preference to plasma spray and the proprietary D-Gun spray processes.

Wire-Arc Spray

Process. Wire-arc spray processes utilize the DC electric arc to directly melt consumable electrode wires, as schematically shown in Figure 23. Unlike the other thermal spray processes which indirectly heat the particles through heated gas jets. Thus the thermal efficiency of the wire-arc spray is higher than that of all the thermal spray processes. In wire-arc spraying, electric current is carried by two electrically conductive, consumable wires with an electric arc forming between the wire tips in the gap where the two wires are continuously being converged. A high-velocity air jet blowing from behind the moving wires strips away the molten metal which continuously forms as the wires are melted by the electric arc. The high-velocity air jet flow ranges from 300 to 3,000 slm (40 to 410 scfh). It breaks up or atomizes the molten metal into finer particles in order to create a fine distribution of molten metal droplets. The atomizing air then accelerates the particles away from the electrode tips to the substrate surface where the molten particles impact the substrate to incrementally form a coating. Note: unlike combustion or plasma spraying, the droplets are already molten when the material enters the jet, and are being continuously cooled by the atomizing air as the particles leave the arc zone. Thus, the optimized wire-arc spray process attempts to shorten the time of flight in order that the air jet cooling effects on the

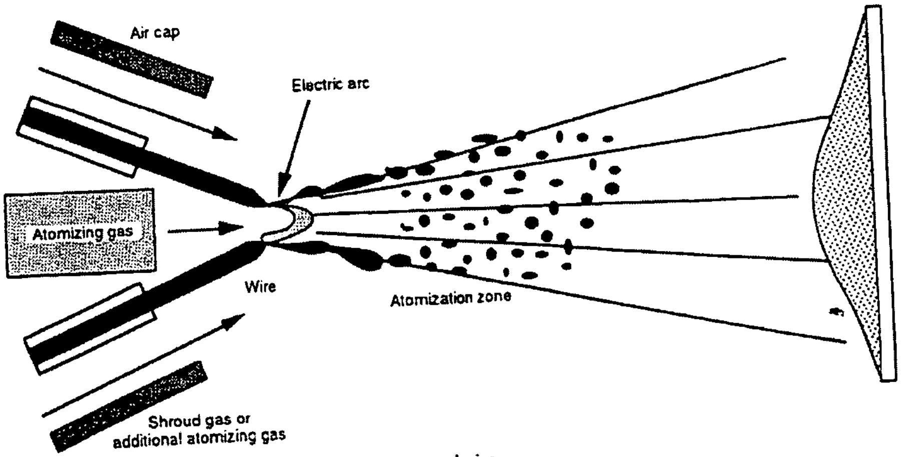


Figure 23. Operational principles of a two-wire-arc spray device.

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